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A review of China's road traffic carbon emissions

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ABSTRACT

Road traffic is one of the main sources of carbon emissions that cause climate change. Despite numerous studies on road traffic emissions, significant challenges remain in carbon emissions measurement and quantitative evaluation of mitigation effects. This paper first reviews the measurement of carbon emission from road traffic including the top-down model and the bottom-up model. Then, we summarize the main factors that affect the traffic carbon emissions, which are divided into three categories: demand side factors, supply side factors and environmental measurement factors. Finally, traffic mitigation measures from economic, technical and administrative aspects are examined. Based on the review, we can conclude that the results of carbon emissions calculated by different methods are quite different, and there are differences in the accuracy and application scope of various methods. Each type of factor plays a different role in the process of traffic reduction, in which the demand factors are the roots, the supply factors are the means, and the environmental factors are the conditions. The development of traffic mitigation measures is not targeted, and there is a lack of quantitative research on policy effects. In the future, it is necessary to standardize the statistical caliber and error standard of measurement of carbon emission for road traffic, and to clarify the responsibility of emission reduction from various traffic subjects. More research efforts need to be focused on quantifying the effect of mitigation measures.

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1. Introduction

Road traffic is one of the major contributors to the carbon emissions that cause climate change. Nearly 25% of the world's energy-related carbon dioxide (CO_2) emissions are generated by the transport sector each year, of which 75% are from road traffic. In 2015, China's transportation sector produced 843.9 million tonnes of CO_2, accounting for 9.3% of the country's total emissions, of which 698.3 million tonnes originated from road traffic (IEA, 2017), and these emissions are increasing annually (Fig. 1). Therefore, an improved understanding of China's road traffic carbon emission status and mitigation measures to achieve reduction targets is of great significance.

Due to the lack of official statistics on CO_2 emissions in China, many studies have focused on carbon emission measurement (Hao et al., 2015; Schmidt et al., 2014; Javid et al., 2014). Various measurement models of carbon emission from road traffic have been developed and applied, which are mainly divided into the top-down model and the bottom-up model. Reliable measurement of carbon emissions is a prerequisite for objectively assessing the contribution of road traffic to climate change. Because of the inconsistency of the modelling principles and the quality of indicators, the carbon emissions calculated by different methods differ greatly (Zhang et al., 2014; Wang et al., 2011), and cannot provide clear estimates of road traffic CO_2 emissions.

Formulating appropriate mitigation measures to achieve effective reduction of CO_2 output from road traffic is the ultimate goal of researchers. To formulate effective emission reduction measures, it is particularly important to analyze the factors affecting the carbon emissions from road traffic. There are many studies on these factors (Timilsina and Shrestha, 2009; Zhang et al., 2014; Loo Becky and Li, 2012). However, current research on the influencing factors is focused on one aspect or a specific stage of the carbon emission process, and a systematic review of the factors affecting the entire emissions process is lacking (Wang et al., 2014a, b). Only on the basis of systematic analysis of the factors influencing road traffic carbon emission can we grasp the role of each factor in traffic emission reduction, clarify the responsibility of emission reduction from various traffic subjects, and provide clear implementation objectives for the development of emission reduction measures (Glassom, 2007).

Emission reduction measures are also a research focus of road traffic carbon emission studies. The existing literature mainly provides policy makers with mitigation policy recommendations based on qualitative analysis from the perspectives of economy, administration, technology, and publicity (Jou et al., 2012; Li et al., 2016a, b; Burris et al., 2012). However, quantitative research on the policy effects is still lacking. In general, the theoretical effect of mitigation measures is often better than their actual effect (Huo et al., 2012). For example, the odd-and-even license plate rule will theoretically reduce 50% of the vehicles in use and halve road traffic carbon emissions. However, the residents offset the emission reduction effect of this policy by increasing the non-limited travel time, or by purchasing a second car, and the actual effect is far lower than the theoretical effect (Viard and Fu, 2015). The quantitative research on policy effects is the basic way to objectively evaluate various policies, and is also the main reference for policy making (Paravantis and Georgaakellos, 2007). Examining policy features, clarifying policy subjects, and comparing policy theory effects are the basic preconditions of quantitative research on policy effects. Therefore, reviewing research on traffic reduction policies has a significant importance for future quantitative research on policy effects.

This review aims to reconcile the various studies that have been reported around road traffic carbon emissions, and evaluate some characteristics of carbon emission measurement, as well as influencing factors and mitigation measures, and highlight areas with future research potential. In summary, the key questions that we hope to address through this review article are as follows. (1) What are the characteristics of various traffic carbon emission measurement methods? (2) What are the traffic subjects of different types of influencing factors, and what are the corresponding emission reduction responsibilities of each subject? (3) What are the characteristics of each type of road traffic mitigation measure and what is the implementation objective of the measures? Based on those questions, we compare and analyze the advantages and disadvantages of various carbon emission measurement methods, which will be helpful to the future standardization of road traffic carbon emission measurement techniques. The factors influencing road traffic carbon emission are divided into supply side factors, demand side factors and environmental side factors, which help clarify the responsibility of emission reduction from various traffic subjects. Elaborating the characteristics of various traffic reduction measures lays a foundation for the quantitative research of policy effects. The specific article structure is shown in Fig. 2.

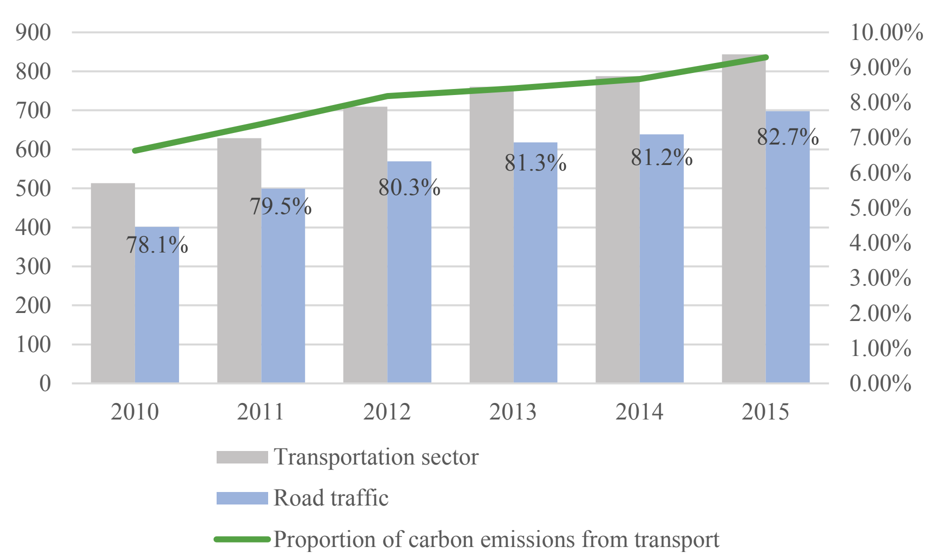

Fig. 1. Carbon emissions from China's transportation sector.

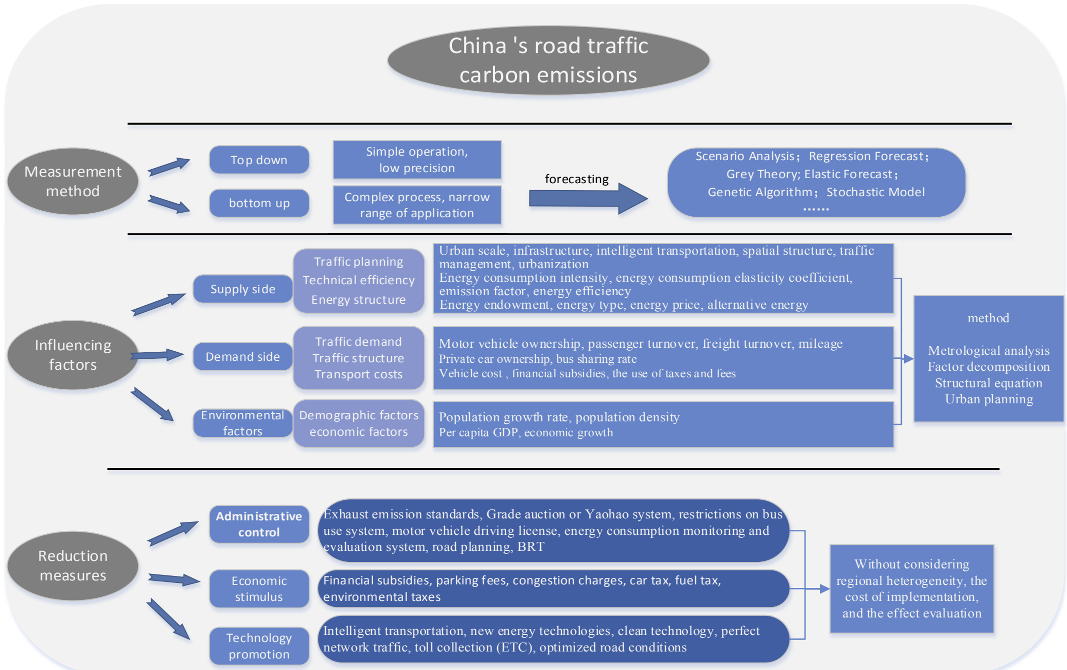

Fig. 2. Structure of the article.

2. Methodology

The need to shift to a low-carbon energy system has become a global consensus, and despite a 50% reduction in global carbon emissions growth over the past two decades, the total emissions continue to grow and are predicted to increase by 20% between 2014 and 2035. As one of the major carbon sources, the transportation industry consumed more than 67% of the global liquid energy; thus, transitioning to a low-carbon world and developing low-carbon traffic is imperative (IEA, 2017). Road traffic is the main component of the transport sector and has aroused widespread concern in the research community as well as among policy makers.

An article search for research papers published in peer-reviewed journals was conducted using the databases Web of Science® and China National Knowledge Internet (CNKI). CNKI is a digital library initiated by Tsinghua University and Tsinghua Tongfang Co., Ltd., founded in June 1999. CNKI has developed into an internationally advanced publishing platform that contains journals, doctoral dissertations, master's theses, conference papers, newspapers, reference books, yearbooks, patents, standards, Sinology, and international literature. The search focused mainly on studies from the year 2000–2015 using keywords that included “transport carbon emission” and “road transport”, and excluded literature related to emissions from waterways, airways and railways. From these, 5290 studies published in English and 238 studies published in Chinese were identified in the Web of Science® and CNKI, respectively (Fig. 3).

From the search results, road traffic carbon emissions have been discussed by international scholars since the early 21st century, and the number of published studies has maintained a stable growth trend for nearly 15 years, during which the total amount of literature increased by nearly five times. According to the number of articles in the top ten regions (Table 1), most (35.86%) of the traffic-related carbon emissions research has been conducted in the United States, followed by that in China, Germany and the United Kingdom. In terms of research areas, international studies mainly

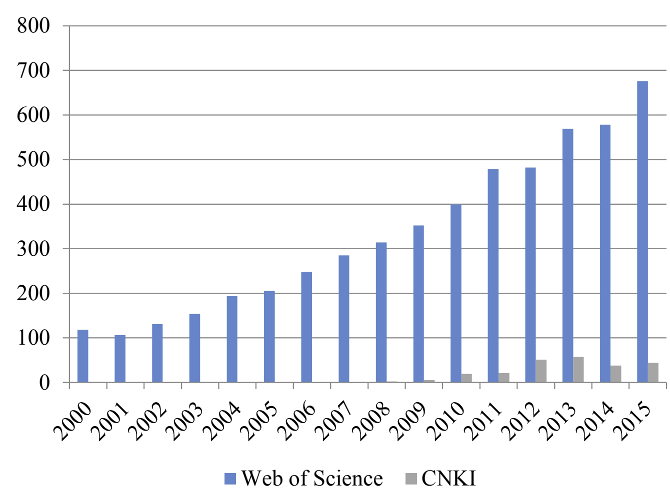

Fig. 3. Number of published studies on road traffic carbon emissions, as identified in the Web of Science® and CNKI.

have concentrated on climate, environment, energy, project management and other fields. In contrast, China's domestic research on the issue started relatively late, and the total amount of 238 studies were published mainly after 2010. Therefore, China's carbon emissions research needs to be further analyzed and improved.

3. Research on China's road traffic carbon emissions

3.1. Measurement of carbon emissions from road traffic

China's traffic carbon emissions accounted for more than 8% of the total carbon emissions; although this proportion is not high from a statistical point of view, it may be underestimated because the statistical standards used in the various data sources were different, and the carbon emissions from the non-traffic sector of

Table 1
Origins and topics of published papers on road traffic carbon emissions.

Country	Number of papers	Research area	Number of papers
USA	1740	Meteorology Atmospheric Sciences	1259
China	684	Environmental Sciences Ecology	1239
Germany	573	Engineering	607
England	506	Physics	440
Japan	415	Energy Fuels	390
France	410	Science Technology Other Topics	357
Canada	276	Materials Science	307
Netherlands	249	Chemistry	295
Italy	225	Geology	257
India	212	Agriculture	139

social vehicles were not included. Consequently, China's traffic carbon emissions are seriously underestimated. China's carbon emissions data illustrate difficulties that exist worldwide in determining the magnitudes of these emissions. “Traffic carbon emissions” mainly refers to mobile source emissions. Compared to fixed source emissions from industry and construction, traffic carbon emissions have greater uncertainties in measurement, emission characteristics and evolution trends. Internationally, the methods of estimating carbon emissions are based on direct measurement, material balances or emission coefficients (Auffhammer and Carson, 2008); the latter two methods are the main ways to measure carbon emissions from fossil fuel consumption. According to the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), mobile source carbon emissions computational methods can be compartmentalized into a top-down model and a bottom-up model. The two types of estimation models can be used to calculate total emissions or emissions in different traffic modes under the different research objectives.

The top-down modelling method is based on energy consumption and energy conversion factors to calculate carbon emissions from transportation, as described by Eq. (1). In Eq. (1), E represents the traffic carbon emissions, i is the type of fuel, EF_i is the carbon emission factor, and V_i denotes the fuel consumption. The method has been widely used in traffic emissions calculation (Wang et al., 2012; Zhang et al., 2014).

$$E = \sum_i EF_i \times V_i \tag{1}$$

The bottom-up model is based on the “activities-traffic-weight-density-fuel consumption” concept of Schipper et al. (2000), and uses different travel modes, vehicle types, ownership, travel distance, unit fuel consumption and other data to measure transport energy consumption. The basic bottom-up model is described by Eq. (2).

$$T = \sum_{ij} V_{ij} \times D_{ij} \times C_{ijt} \times F_{ij} \tag{2}$$

In Eq. (2), T represents the traffic carbon emissions, i represents the vehicle type (such as cars, buses, motorcycles, diesel locomotives, steam locomotives, ships, aircraft, etc.), j is energy type (such as gasoline, diesel, kerosene, natural gas, etc.), V_{ij} is the number of vehicles i that use energy source j, D_{ij} is the distance traveled for a certain period of time for the vehicle i using the energy source j, C_{ij} is the average energy consumption of the vehicle i using the energy source j, and F_{ij} denotes the carbon emission factor of the vehicle i using the energy source j. As Eq. (2) indicates, carbon emissions are related to the means of transport, travel distance and energy type. Many studies have used this method of emissions quantification (Pallavidino et al., 2014; Puliafito et al., 2015).

The above two models have advantages and disadvantages. The top-down model accommodates a wide measuring range and can calculate the carbon emissions at spatial scales ranging from national to sub-provincial, and even for sub-types of transport fuel and comparisons between regions. Furthermore, the top-down model calculation is simple in the case of known energy consumption. Unfortunately, the top-down model is based on traffic energy consumption data, which are then multiplied by a corresponding carbon emission factor to estimate the final traffic carbon emissions. In addition, there are no agreed standards for determining the energy carbon emission coefficient, limiting the accuracy of carbon emission estimates using the top-down model. The bottom-up model is theoretically accurate and reflects the characteristics of mobile source emissions. However, this method requires data such as vehicle type, travel distance, unit fuel consumption, and energy consumption per unit distance of travel. These data are generally obtained by investigation but only in small geographic areas, which increases the uncertainty of the calculation and results in relatively poor comparability between regions. With global warming worsening, countries are responsible for strict control of carbon emissions, and the requirements of measurement is no longer extensive and local, but should be accurate and systematic.

On the basis of measuring the carbon emissions of road traffic, it is necessary to understand the trend of carbon emissions and provide a scientific basis for the corresponding carbon reduction targets in each region. The scenario analysis method is widely used to forecast traffic carbon emissions, and uses a simulation system or mathematical model to analyze the changes of carbon emissions in different scenarios such as policy intervention, technological progress and traffic structure changes (Ou et al., 2010; Hao et al., 2011), and then put forward an effective mitigation strategy. Ou et al. (2010) presented an analysis of alternative fuel vehicles for future road transport in China, predicting energy demand for the entire life cycle and the accompanying greenhouse gas emissions. The regression prediction method is also used in carbon emission forecasting. Liu (2011) used the linear regression method to forecast the traffic volume of China's transportation sector, and then measured the energy consumption and carbon emissions. Scenario analysis has the advantages of both qualitative analysis and quantitative analysis, but requires accurate analysis of the internal and external environment of transportation; furthermore, setting of the scenario is subjective. The regression prediction method is strongly dependent on the degree of curve fitting, and it is necessary to set the parameters in advance. Gray theory, elastic prediction, partial least squares regression, multi-layer genetic algorithms, stochastic modelling, system dynamics and other techniques have also been used to analyze carbon emissions.

Energy consumption statistics in China's transportation sector include only public operations, and a large number of non-

commercial vehicles are excluded, especially in the rapidly growing category of private cars, for which the calculated carbon emissions from road traffic are significantly underestimated. The complexity of the transport system, coupled with the fact that traffic carbon emissions are mobile carbon sources, increases the difficulty of measuring carbon emissions (Schmidt et al., 2014). However, measurement is the basis of research that provides a scientific basis for follow-up actions in terms of developing emission reduction targets and implementing emission reduction measures. Therefore, improvement of traffic carbon emission measurement methods is urgently needed. The idea of a combinatorial strategy can be taken into account; the combined use of several methods can avoid the error arising from use of a single method, and reduce the overall error, thereby smoothing the error scope (Javid et al., 2014).

3.2. Influencing factors

3.2.1. Factor indicators

Road traffic carbon emissions are the results of multi-factor interactions. Research on these mechanisms plays a key role in the development of emission reduction pathways and mitigation measures. Studies on road traffic emission factors are relatively abundant, but the research content and the purposes of the studies are not the same, and each of these studies focuses on one or a few specific aspects of road traffic emissions. As a result, the specific influencing factors that have been studied vary widely, including energy structure, traffic planning, technical level, demand management and external environment, among others. In this study, the various factors were categorized into supply factors, demand factors and environmental factors according to different traffic subjects (Table 2). The purpose of our classification is to clarify the traffic subjects corresponding to various influencing factors. Supply factors are analyzed from the perspective of transportation service provision, including traffic management, infrastructure construction, technical support, and energy supply. The main subject of the transportation system for such factors is the provider of transportation services. The demand factor is analyzed from the demand for transportation services, including some transportation consumption characteristics, such as travel characteristics, travel structure, travel costs, etc. The main subject of the transportation system for such factors is the demander for transportation services. Since the development of the transportation system is inseparable from the external environment, the transportation system interacts with the socio-economic system. Environmental factors mainly refer to the impact of economy and population on traffic carbon emissions. The main subject of such factors is the external environment of the transportation system. Classifying the influencing factors according to the traffic subject will help the government clarify the emission reduction responsibility of various traffic subjects when formulating a traffic emission reduction policy, ensure the implementation of the emission reduction policy, and improve the effect of the emission reduction policy.

(1) Supply factors. The supply factors are summarized as traffic management factors, traffic technology factors and traffic energy factors. Traffic management factors include government-initiated development plans that take into account the characteristics of a city and the needs of city development, including urbanization, city spatial structure, traffic planning, and operational management, among others. Traffic management factors reflect the convenience and efficiency of travel from the perspective of government management, and affect the travel mode and travel efficiency. Thus, in theory, expanding existing road capacity can reduce traffic-related emissions (Schrank et al., 2010). In practice, scientific road planning that improves the connectivity of intersections and enhances the initiative of a traffic management system, has been shown to significantly alleviate congestion and achieve the same effect as traffic reduction (Glassom, 2007). In recent years, China has

Table 2
Categorization of factors influencing road traffic carbon emissions.

Study factors	The second level factor	Specific factors	Relevant articles
Supply factors	Traffic management	City scale City planning Smart traffic Infrastructure Traffic operations management Urbanization	Zhang and Nian (2013), Zhang et al. (2018), Phu (2010), Reckien et al. (2007), Kenworthy and Laube (1996), Hughes et al. (2004), Newman (2006), Wang et al. (2014a, b)
	Transportation technology	Energy consumption intensity consumption elasticity coefficient Emission factor Energy efficiency	Wu et al. (2005), Huo et al. (2012), Dray et al. (2012), Wang et al. (2011), Timilsina and Shrestha (2009), Arvin (2015), Sumaedi et al. (2016), Raslavičius at al. (2015), Spielmann et al. (2008)
	Transportation energy	Geographical position Energy type Energy price Alternative Energy	Zhang et al. (2014), Huo et al. (2012), Cheng et al. (2015), Litman. (2008), Li et al. (2016a,b), Huo et al. (2013), Al-Alawi and Bradley (2013), Song et al. (2016)
Demand factors	Traffic demand	Vehicle fleet Passenger turnover Freight turnover Travel distance	Auffhammer and Carson (2008), Wu et al. (2005), Wang et al. (2011), Chai et al. (2015), Huo and Wang (2012), Su and Ang (2012), Wu et al. (2017)
	Traffic structure	Private car ownership Bus sharing rate	Reckien et al. (2007), Dray et al. (2012), Su and Ang (2012), Paravantis and Georgaakellos (2007), Johansson (2003)
	Transportation costs	Economic cost Financial subsidy Taxes and fees	Burris et al. (2012), Jou et al. (2012), Song et al. (2014), Wu et al. (2017)
Environmental factors	Demographic factors	Population growth rate Population density	Phu (2010), Büchs and Schnepf (2013), Wang et al. (2011), Timilsina and Shrestha (2009), Batterman et al. (2014)
	Economic factors	Per capita GDP Economic increment	Phu (2010), Büchs and Schnepf (2013), Timilsina and Shrestha (2009), Arvin (2015)

accelerated the process of urbanization, which in raising the living standards of residents, has also promoted the rapid increase in traffic energy consumption and increase in greenhouse gas emissions (Liu and Xie, 2013; Poumanyvong and Kaneko, 2011).

Traffic technology factors include all the technical problems involved in the process of road traffic management, including vehicle technology, energy technology, etc., and have a direct impact on carbon emissions for a certain travel demand. Energy factors are the basis for carbon emissions. Technology plays an increasingly important role in traffic reduction. At present, the production of vehicles requires light design, ultra-low resistance, and higher fuel efficiency (EPA, 2016; Correia et al., 2014). Moreover, emission factors also play a significant role. The carbon emission coefficient of various types of energy is different. With the development of technology, traditional fossil energy is slowly being replaced by new energy, and the emission intensity of greenhouse gases is gradually being reduced (Li et al., 2014). In addition, reducing the inertia of vehicles under low-speed conditions, improving fuel efficiency, and reducing the resistance during high-speed operation, as compared to a decade ago, have resulted in lower energy consumption and better emission reduction (Liu et al., 2016). Engine size is also a key factor; generally smaller engines consume less fuel and emit fewer emissions than larger engines.

Energy consumption is the precondition of traffic carbon emission. Energy indicators are the basis for measuring carbon emissions, including energy structure, energy efficiency and other energy indicators that reveal the characteristics of vehicle energy consumption. These indicators are closely related to traffic demand, travel mode and other variables. Energy is the basis for ensuring the normal operation of the transportation industry. In China, energy prices, alternative energy sources, and energy types are constrained by government regulations and existing conditions. Therefore, the corresponding traffic subject of energy factors is the provider of transportation services. Furthermore, there is a significant correlation between local energy supplies and energy consumption habits, such that traffic carbon emissions have obvious spatial features. However, with the increasing scarcity of traditional energy and the rapid development of technology, the regional characteristics of vehicle energy consumption are becoming less obvious, and alternative energy is playing an increasingly important role. Currently five types of motor vehicles are marketed according to their fuel type, namely, traditional fossil-fueled vehicles, alternative fuel vehicles, hybrid vehicles, pure electric vehicles and fuel cell vehicles (Fig. 4). With the development of automotive technology, the traditional high-emission vehicles are gradually being replaced by low-emissions alternative fuel vehicles. Due to positive environmental benefits and strong government support, the electric vehicle penetration rate rising. But the current popularity of electric vehicles in China is not high. A very important reason for the low popularity is the lack of adequate charging facilities; moreover, the cost of electricity and hydrogen fuel is relatively high (Lovins and Cramer, 2004; Li et al., 2016a,b), which also hinders the development of the electric vehicle industry, such that the traditional fossil-fueled vehicle in the Chinese market still dominates (Moriaty and Honnery, 2004).

(2) Demand factors. These factors are considered from the direct consumption subject, which mainly consists of traffic turnover (including passenger and freight), traffic structure and traffic costs. With socio-economic development, travel efficiency continues to improve, and social traffic demand has also undergone great changes, including higher traffic frequency, longer travel distances, a greater variety of traffic modes, and lower traffic costs. Changes in traffic demand have a direct impact on traffic emissions, and an increasing travel demand will directly stimulate a rise in vehicle ownership. In 2014, China's passenger car ownership was 86 per thousand of population, compared to 300–500 per thousand in developed countries; thus, there is still much room for growth. Traffic costs are an important factor in stimulating consumer demand; therefore, the application of economic measures (including subsidies and flexible use of taxes and fees) to bring about traffic reductions has become a common practice in most countries.

Referring to the experience of developed countries, when per capita GDP reaches US$3000 to US$4,000, there will be a peak in

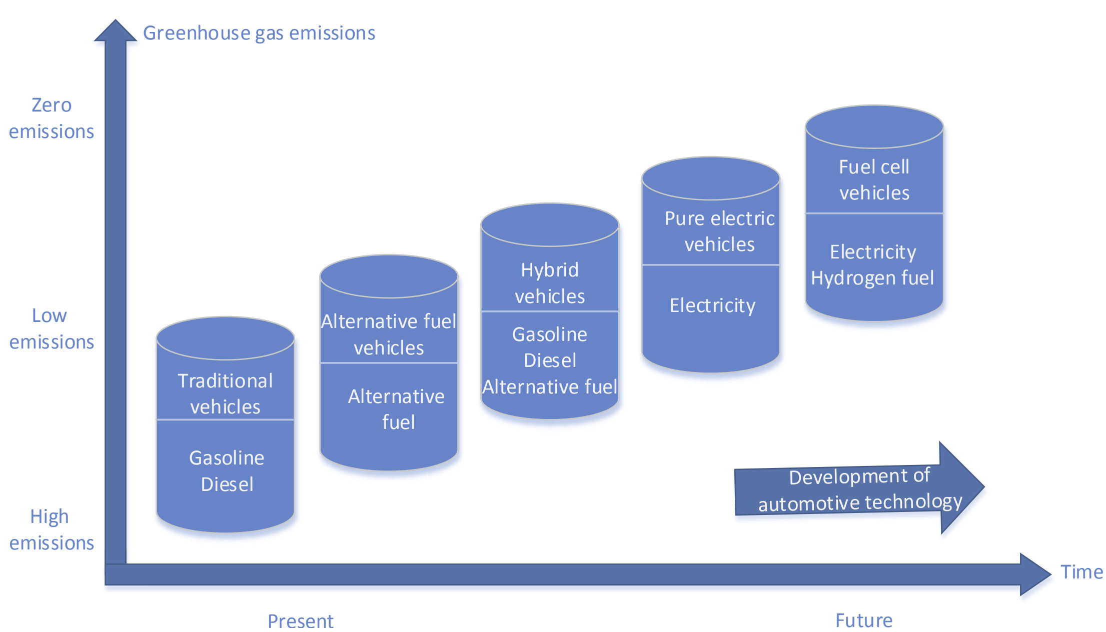

Fig. 4. Classification of vehicles in terms of fuel source and emissions.

motor vehicle purchases. Car ownership increases with the development of the economy and improvement of per capita GDP (IEA, 2017); therefore, China's road traffic carbon emissions will exhibit an upward trend. In addition to direct carbon emissions from vehicle operations, the associated activities of vehicle manufacturing, maintenance and road construction, and parking lot construction will also consume energy, resulting in increased greenhouse gas emissions. A substantial increase in private car ownership will trigger a large demand for land space, resulting in competition among private cars, pedestrians, bicycles and buses for road space, and reduce, to some extent, the proportion of total travel satisfied by public transport. Effective traffic demand management policy is based on the management of motor vehicle growth to guide the rational use of private vehicles and reduce the total private vehicle travel distance. Advocating the use of carpools, and encouraging companies to provide shuttle services, are effective ways to reduce the number of motor vehicles in use (Glassom, 2007; Geng et al., 2016).

There are differences in the resource consumption and environmental costs required for various traffic modes. As motorized service tools, motor vehicles have higher energy intensity use than non-motorized vehicles and public transport, and are the cause of most city transport energy consumption and carbon dioxide emissions. Public transport is a widely accepted low-carbon travel approach that can achieve significant emission reductions (Su and Ang, 2012). Diversified traffic modes are conducive to achieving traffic emission reductions; however, diversification requires the availability of reasonable modes of travel, promotion of non-motorized transport (such as walking or bicycling), and alternating vehicle travel demand with the use of a public transport system.

Travel costs have a great impact on traffic demand, and can be divided into fixed costs and variable costs. China's fixed costs include asset consumption, purchase tax, license fees, travel tax, city tolls, insurance, fixed parking fees, and inspection fees. The variable costs refer to the oil costs, temporary parking fees, maintenance costs, illegal tickets, and congestion charges; however, for public transport, the cost refers only to the ticket cost. Compared with international practice, the current fixed cost of private traffic in China has been relatively high with little room for growth; however, with personal income projected to improve, the fixed cost of the control role is gradually offset. Studies have shown that variable costs have a significant effect on private car ownership and travel distance, and because private cars are sensitive to changes in oil prices, oil prices have a significant impact on public transport share rate (Geng et al., 2017). Increasing the temporary parking fees and congestion charges can also achieve good results (Burris et al., 2012; Jou et al., 2012).

(3) Environmental factors. Environmental factors reflect the external environment in which the transportation depends, in terms of both demographics and economic development. Demographic factors include population density and population growth rates, and economic factors include per capita GDP and economic growth. Population growth inevitably leads to an increase in traffic turnover, direct expansion of traffic demand, and increased traffic pressure. With the acceleration of urbanization, the area of urban built-up areas has been expanding, which has led to an increase in the distance traveled by urban residents in China. Studies suggest that population growth has two effects that increase carbon emissions, namely, an increase in carbon sources and a relative reduction in carbon sinks. That is, an increasing population stimulates a greater demand for energy and the resulting carbon emissions are increased. Population growth also makes deforestation more serious and changes the use of land, which removes carbon sinks and increases the impact of carbon emissions.

In general, the growth of the economy and the improvement of incomes are often accompanied by the increase of motor vehicle ownership, traffic flow, travel distance and travel frequency. Changes in income impact the choice of travel demand and the adjustment of lifestyle. Population growth and economic development promote traffic demand and increase road transport carbon emissions (Phu, 2010; Timilsina and Shrestha, 2009; Darido et al., 2009). However, the development of the economy and urban road traffic carbon emission reduction are not contradictory objectives. Studies have shown that the increase in the per capita GDP growth rate in the previous period in China has greatly increased the current carbon emissions, but the long-term effect of increasing per capita GDP is conducive to reducing carbon emissions (Zhang and Zeng, 2013).

3.2.2. Methods for analyzing influencing factors

Research on influencing factors analysis can be carried out mainly from two aspects. One approach is to explore the relationship between carbon emissions and factors, for which econometric analysis and decomposition analysis are commonly used. The other approach is to analyze the evolution of economic growth and transport carbon emissions to determine whether the economic growth and carbon emissions meet the environmental Kuznets curve (EKC) (Nassani et al., 2017; Kaika and Zervas, 2013). Current research is mainly focused on the former.

(1) Econometric analysis is based on the establishment of an equation to relate environmental impact to population, affluence and technology (IPAT equation) (Ehrlich and Holdren, 1970) or its stochastic relative (STIRPAT model) (Dietz and Rosa, 1997) to perform multivariate regression analysis of each factor, with the regression coefficient reflecting the degree of influence. Ehrlich and Holdren (1970) proposed the IPAT model, which is an identity. When examining a specific level of population, income, and technology, the combined impact of these three factors on the environment is flexible, and the effect of each factor cannot be distinguished. To address this shortcoming, Dietz and Rosa (1997) developed the regression-based STIRPAT model, which included a random term. Darido et al. (2009) analyzed 17 Chinese cities in terms of population, population density, per capita GDP and other features, and found that increased population and income leads to increased numbers of motor vehicles and growth in passenger turnover. Furthermore, city expansion and complex population density increase travel distance and because people prefer motor vehicles as their mode of travel, city traffic carbon emissions increase. Liao et al. (2011) used multiple regression models to estimate the carbon dioxide emissions from inland container transport between 1998 and 2008, and found that GDP and oil prices were the main influencing factors. Compared with the IPAT model, the STIRPAT model does not limit the number of variables that can be examined and does not require the same change ratio in emissions and dependent variables. These improvements allow the STIRPAT model to better identify the explanatory ability of each driving factor, but the drawback is that the model cannot prove there is a real causal relationship between the driving factors and greenhouse gas emissions.

(2) Decomposition analysis. In addition to regression analysis, decomposition analysis is an important method to study the

interaction mechanism of traffic carbon emissions, and commonly includes structural decomposition analysis (Ang and Liu, 2007) and index decomposition analysis (Ang et al., 1998). Structural decomposition analysis is based on an input-output table, and decomposes the changes in the analyzed objects into several basic factors, which are clearly traced back to the root of the analysis of the object, and the impact of the various basic factors. However, there are some defects in structural decomposition analysis, one of which is that it uses only the additive form of decomposition. Index analysis data requirements are low, and relationships are easy to analyze empirically. Based on different algorithms, index analysis can be divided into Laspeyres decomposition (Sun, 1980), logarithmic mean divisia index (LMDI) (Ang et al., 1998; Tolón-Becerra et al., 2012; Meng et al., 2015) and adaptive weighting division. Wu et al. (2005) discussed the influencing factors of traffic carbon emission growth using LMDI that was based on the data from China's provinces, and concluded that traffic energy intensity, average travel distance and motor vehicle volume were the driving factors of emission growth. Guo et al. (2014) analyzed the differences between regional carbon emissions in China using the LMDI, and concluded that the intensity of carbon dioxide emission in the eastern transport sector is lower than that in the western region.

Some studies have also applied other methods for factor analysis, such as the structural equation method (Singh and Sharma, 2014), and have also conducted research from the perspective of planning to discuss the relationship between city space layout and traffic emissions (Phu, 2010). The qualitative and quantitative analysis of the influencing factors is helpful for formulating specific emission reduction measures, which play an important role in the direction and effect of emission reduction.

3.3. Mitigation measures

Road traffic as a major source of greenhouse gas emissions, making the implementation of energy saving and emission reduction imperative. China's low-carbon transport is facing many problems, such as the lag in the development of public transport, the significant increase in the motorization of travel structure, the lack of effective demand management, the weak awareness of energy conservation and emission reduction, and the lack of coordination between the traffic management system and low carbon transport.

Central and local governments have formulated a number of policies to guide traffic energy conservation. For example, in the Energy Law of 2016 (Energy Law, 2016), Chapter III separates the transport sector to facilitate a series of emission reduction policies, such as encouraging the development of environment-friendly cars (small displacement) and promoting new-energy vehicles. In recent years, many policies and measures have been implemented to effectively control the carbon emissions of China's traffic. On the whole, the means of road traffic reduction can be divided into three categories, namely, administrative control, economic stimulus and technology promotion (Fig. 5).

Administrative control needs to establish strict rules and regulations, including reasonable planning standards, a strict motor vehicle access system, tail gas discharge standards and regulatory systems. Administrative techniques can also strengthen traffic energy management, improve the relevant traffic energy standards, establish and improve the evaluation system of energy efficiency and enhance emission reduction. The license auction system is used to control the number of motor vehicles, increase the incentive to actively develop rapid transit, encourage travelers to abandon inefficient private car travel and instead use efficient public transport, improve vehicle energy consumption and emission standards, and develop and implement mandatory fuel efficiency specifications. Administrative techniques also can assure exhaust detection is strictly conducted, effectively strengthen the coordination between the various departments to eliminate vehicles that have failed exhaust emissions testing, and actively promote energy conservation.

Economic measures can give full play to the role of economic leverage and strengthen the automobile control policy. The

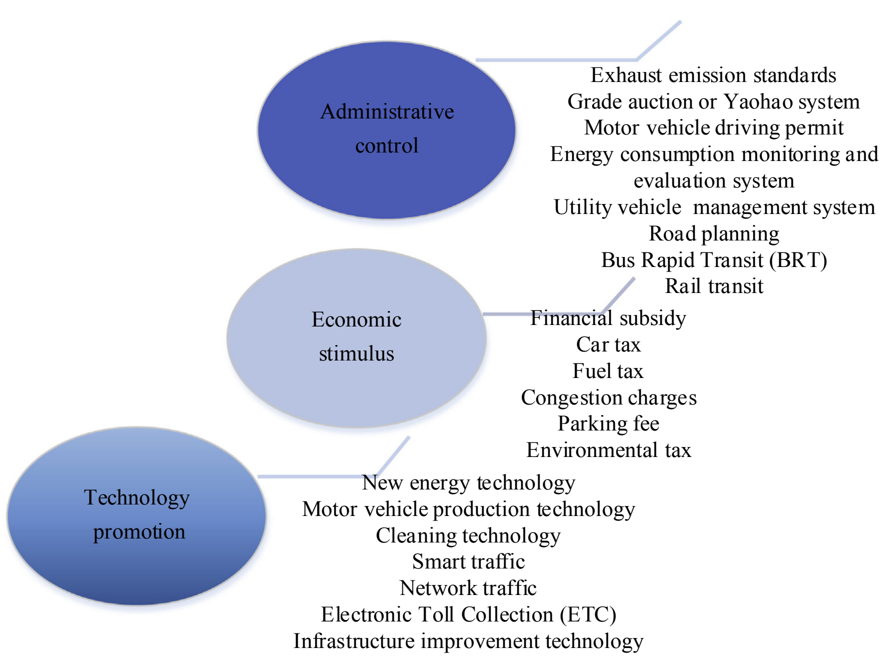

Fig. 5. Road traffic reduction measures.

measures include reducing the purchase tax on environment-friendly vehicles to stimulate consumption, changing the parking and congestion charges to limit use of private cars, subsidizing buyers of alternative-fuel vehicles, and implementing differential tax rates according to vehicle characteristics, such as engine displacement size and motive category (Mitchell, 2005). However, some studies have shown that indirect taxes cannot achieve emission reduction targets (Geng et al., 2016).

In the technology area, optimizing vehicle design is an effective mitigation measure, such as improving vehicle energy efficiency and reducing running resistance. Developing alternative energy technologies is another appropriate technique, which includes promoting the use of alternative-fuel vehicles (Li et al., 2016a,b). In addition, the development of other technologies can also reduce traffic demand. For example, the development of electronic communication technology makes it possible for companies to encourage people to adopt flexible ways of working, such as working from home, video conferencing, and greater reliance on telephone communication. Smart transportation also plays an important role in emission reduction.

To achieve the goal of traffic reduction, it is important to reasonably guide traffic demand, optimize the transportation structure, increase vehicle efficiency and improve the traffic management system mechanism (Sumaedi et al., 2016). Road traffic reduction is arduous; achieving emission reduction targets needs to meet environmental, economic and social benefits simultaneously. The current Chinese policy has a certain emission reduction effect, but the concrete implementation process lacks systematic thinking, does not consider the policy interaction influence, and fails to include an implementation effect appraisal. The development of emission reduction measures needs to consider the heterogeneity of the region. There are great differences in economic development, population, resource endowment and residents' demand in different areas, and the current situation and development trend of traffic carbon emission are quite varied. More effort is required to achieve emission reduction targets. The period 2010 to 2020 is one of rapid development of China's traffic demand. To meet energy security and greenhouse gas emission reduction requirements, China needs to implement more stringent industrial and environmental policies (Huo and Wang, 2012). It also is necessary to restrict the use of fossil fuels and strengthen environmental control systems to ameliorate air quality deterioration in China (Huo et al., 2013).

4. Discussion

Road traffic carbon emissions research is difficult because the actual carbon emissions cannot be known, and the accuracy of measurement is difficult to guarantee. Therefore, research on influencing factors and emission reduction policies is also difficult. Although there is much literature on the measurement method of traffic carbon emissions, due to the combined effects of various factors, traffic emissions are highly variable. For example, even if the same car travels the same distance multiple times, the resulting carbon emissions during each journey are likely to be different because of the driver's driving habits and/or traffic conditions (Shao et al., 2017). Therefore, there are many uncertainties in the research conclusions about traffic carbon emissions in the existing literature.

(1) The measurement of road traffic carbon emissions. The methods widely used in traffic carbon emissions measurement are the top-down model and bottom-up model. The former is based on traffic energy consumption data which are then multiplied by a corresponding carbon emission factor to estimate the final traffic carbon emissions. The top-down model requires accurate traffic energy consumption data, but the current energy consumption statistics in China are industry-based, and the energy consumption of some non-transportation social transport vehicles is not included (Zhang et al., 2018). Therefore, energy consumption statistics significantly under-represent the actual consumption; furthermore, there is no uniform standard for the determination of carbon emission factors, and the accuracy of traffic carbon emissions is questionable. The bottom-up model requires accurate quantification of specific vehicle types, ownership, travel distances, unit fuel consumption and corresponding carbon emission factor data. Thus, although the bottom-up model is theoretically more accurate than the top-down model, the data requirements of the former are relatively high. Generally, the data are obtained through on-site investigation; considering the cost of such investigations, practical obstacles in conducting the investigations and other issues, the bottom-up model of carbon emissions analysis can be implemented only in a small area. According to China's current statistical system (only including macro data of the transportation industry), the calculation of regional transportation carbon emissions is more suitable for the top-down model, and the calculation results are more accurate than the bottom-up model based on travel distance calculations (Zhang et al., 2017). For the calculation of carbon emissions from urban transportation, data such as travel distance and fuel consumption of different types of vehicles can be obtained through travel surveys of residents, and the bottom-up model can be used for calculation.

Using these two methods requires multiple traffic system parameters, such as emission factors, vehicle type, driving distance, etc. Specific to different micro-subjects, these traffic parameters are not the same everywhere. In the past, most of the studies used the mean value to estimate the parameters, which reduced the accuracy of the measurement results. The existing research on carbon emission measurement of transportation mainly focuses on the calculation of the carbon emission, and analyses the present situation of carbon emission, carbon emission intensity and carbon emission structure, which can reflect the absolute characteristic of transportation carbon emission. But simply describing the absolute amount of carbon emissions is not a measure of carbon reduction targets; it is necessary to supplement the estimate of absolute carbon emissions with research on the relative changes, which first needs to address the calculation method of the relative variability of carbon emissions (Chen et al., 2017). Furthermore, it is also important to study the time series characteristics of transportation carbon emissions, and to grasp the time characteristics as a whole. In addition, in the assessment of road traffic carbon emissions, most of the literature is confined to the study of carbon emissions from vehicles, taking into account only the carbon emissions generated during transportation, and ignoring carbon emissions from the transport system itself.

(2) Analysis of influencing factors. Road traffic carbon emissions are affected by many factors, such as vehicle conditions, road conditions, energy cleanliness, driving habits, etc. The interaction between the influencing factors is the intrinsic driving force for the change of carbon emissions in transportation, which can explain the evolution mechanism of carbon emissions in transportation. These factors cause the road traffic carbon emissions to vary greatly, and even the same factors have different effects on carbon emissions in different scenarios (Javid et al., 2014). The existing research is

still unclear about the subject of road low-carbon transportation energy consumption and emissions, and lacks the tools for quantitative description of urban low-carbon traffic subjects. According to the traffic subject, the influencing factors can be divided into supply factors, demand factors and environmental factors. In the contradictory systems of road traffic demand and traffic supply, traffic demand is an active variable that has a decisive influence on the solution of road traffic problems. Therefore, traffic demand should be taken as the starting point and the foothold for studying a road traffic system. If traffic demand cannot be constrained, implementing other techniques is important, such as enhancing the efficiency of transport technology, adjusting the traffic energy structure, improving the travel mode and optimizing the traffic road planning (Li et al., 2016a, b). Chai et al. (2015) pointed out that under the premise of not affecting social and economic development, the general idea of road traffic sustainable development is to analyze the essential attributes of traffic demand, reduce the total traffic demand, and build a high-efficiency traffic demand sharing model.

At present, the research on the indicator system of the factors that influence traffic carbon emission is more comprehensive than previously, but from the research scope and objective, this research should broaden its perspective and take a more macroscopic and systematic perspective. Previous research on China's road traffic carbon emissions has been conducted primarily at country scale or for individual cities, with no inter-regional comparison and regional spatial distribution (Hillman et al., 2011; Wang et al., 2013). The heterogeneity of regional spatial distribution reflects the differences of region in resources, geographical features, human environment, and other factors that have a significant impact on travel mode, traffic fuel and travel habits. Huo et al. (2013) concluded that electric vehicles cannot achieve emission reductions in all regions because from carbon footprint theory, the electricity generation process itself emits significant amounts of greenhouse gases. There are significant regional differences in the extent of economic development, population, resource endowment, and consumer demand, all of which cause differences in traffic carbon emissions and trends. Thus, when developing mitigation measures, policy makers need to consider the heterogeneity among regions.

Current literature about the factors influencing road traffic carbon emission mainly focuses on the process of transportation operation, and only a few have considered the associated impacts of infrastructure construction, maintenance and demolition based on life-cycle assessment when accounting for city rail transit carbon emissions. Thus, there is little research on the road traffic carbon footprint. The energy consumption of the transportation carbon emission system occurs not only in the operation stage, but also during infrastructure construction, maintenance, demolition, and the conversion of basic energy into a vehicle fuel. Analyzing the carbon emissions of a transportation system based on life-cycle assessment is more comprehensive, scientific and objective than other techniques. In addition, the carbon emissions generated by different modes of transportation are also very different. The literature comparing energy consumption and carbon emissions among different modes of transportation is still insufficient.

(3) Traffic emission reduction policy research. The study of road traffic policy is a complicated system, which must consider the car, road network and people-oriented concerns to meet the traffic demand. There is much scientific literature on road traffic reduction policies, mainly for path analysis and policy development. However, few studies have examined the implementation of policy or evaluated the policy effects. The quantitative research on the effects of traffic reduction policies is still insufficient. Emission reduction policies have been proposed from the theoretical level; but, because these did not consider the cost, operability or enforcement feasibility involved in the implementation process, the performance of such policies has been relatively poor in practice (Viard and Fu, 2015). In different regional development stages, the same traffic policy exerts different effects. From the international experience, achieving the development of low-carbon traffic in the road network mainly relies on technical and management measures in the early stage of regional development, while in developed countries where economic development is at a mature stage, mainly information and economic measures are implemented (Schmidt et al., 2014). Furthermore, in-depth policy effect evaluation has not been conducted. The theoretical and practical effects of traffic policies often differ greatly. For example, the odd-and-even license plate rule can theoretically halve the number of motor vehicles in use. However, in the actual implementation process, residents can easily avoid the restriction policy by purchasing a second vehicle, or reduce the impact of the restriction policy by adjusting the travel time (Viard and Fu, 2015). The actual effect of the restriction policy is far less than the theoretical effect. There are many reasons for traffic problems, such as unreasonable urban layout. The formulation of transportation policies should be based on the specific conditions of specific locations. The emission reduction effect of the same policy in different cities is likely to be different. Therefore, on the basis of scientific transportation policy evaluation, policy makers should objectively determine the emission reduction effects of each type of policy and fully consider the stage of the role of transportation policies. When other long-term measures can fully play a role of substitution, policy makers should choose the appropriate exit opportunity, design the exit conditions of the policy, and switch the policy.

In addition, a small amount of literature on traffic policy evaluation mainly uses scenario analysis, which simulates policy effects in specific contexts. However, this approach is too idealistic, and the resulting conclusions are not objective (Song et al., 2012). Finally, traffic mitigation measures are more aimed at passenger transport. Freight traffic is close to passenger traffic in terms of energy consumption, and more policy measures that address carbon emissions from freight vehicles should be introduced (Wang et al., 2012).

5. Conclusions and future outlook

5.1. Conclusions

This study systematically combed and analyzed published literature about the measurement methods, influencing factors, and mitigation measures for carbon emissions from road transport, and obtained the following main conclusions.

(1) At present, accurate measurement of carbon emissions from transportation is still a difficult task, and there is a lack of research on the relative changes of carbon emissions in transportation. The current methods of measuring road traffic emissions mainly consist of producing estimates using a top-down model and a bottom-up model. Because these methods involve a series of traffic parameters that are

estimated and vary among cities, model predictions also vary widely. The data availability and practical operation increase the difficulty of carbon emissions measurement. In addition, the current research on carbon emission measurement is mostly static and ignores the dynamic changes in transportation carbon emissions. It is recommended that current and new emission measurement models incorporate the capability to quantify measurement errors, and that clear guidelines are developed by policy makers with respect to maximum allowable prediction errors. In addition, it is necessary to consider the practical operability of measurement models and evaluate the variables (vehicle type, road conditions, etc.) included in various carbon emission measurement models.

(2) Most of the research on influencing factors selects relevant factors according to specific needs rather than according to a systematic framework, and the conclusions obtained from different studies are very different. In addition, very few studies are classified according to traffic subject; such a classification helps to clarify traffic responsibilities and ensure the implementation of traffic reduction policies. According to the different traffic subjects, the influencing factors can be divided into three types (supply factors, demand factors and environmental factors), in which the demand factors are the roots, the supply factors are the means, and the environmental factors are the conditions. Therefore, reducing the residents' travel demand is the most effective way to reduce the traffic carbon emission. However, to avoid reducing the residents' happiness index, a series of measures, such as optimizing traffic structure, improving energy efficiency and improving the quality of infrastructure, are the main policy orientations of emission reduction strategies. In addition, carbon emissions are generated in the entire transportation system and these cannot be ignored.

(3) Most of the research on traffic reduction policies is based on the theoretical level and lacks quantitative evaluation of actual policy effects. These studies do not consider the interaction between policies, and lack evaluation of the implementation effect. Comparative analysis of different policy effects and comparative analysis of the same policy between different regions are even more rare. Quantitative research on the effect of traffic policies is the most direct way to test the effectiveness of mitigation policies. The current emission reduction measures are designed to achieve specific targets, but their effectiveness is limited (Geng et al., 2018). In addition, the development of traffic reduction measures must consider the feasibility of implementation and establish a reasonable policy evaluation system that ensures measures can achieve the expected emission reduction effect. The formulation of policies needs to be targeted, and more efforts need to be made to clarify the responsibility of emission reduction from various traffic subjects. Combination policy systems must be science-based to achieve the best emission reduction effect, and must consider location-specific characteristics as well as the interaction mechanism between emission reduction targets, policies and individual behavior.

5.2. Future outlook

Climate change is not an issue faced by one country alone, but is a global problem that requires shared responsibility. Correcting the climate problem caused by traffic carbon emissions is a long and arduous task. The foregoing literature review analysis identifies the several topics that require further research.

(1) Carbon emission measurement. As a basis for research, carbon emission measurement methods require further research to improve their accuracy and universality. Current measurement models are inadequate and need further improvement to simplify the calculation process and increase accuracy. Researchers must increase their study of the relative changes in carbon emissions from transportation and the life cycle of traffic emissions.

(2) Traffic carbon footprint. Existing research has focused on the process of transportation operation; however, carbon emissions are generated in the entire transportation system. Therefore, it is necessary to analyze the emissions problem based on a system perspective, using life cycle theory to study the carbon footprint of the entire transport sector.

(3) Future research needs to broaden the scope of research, including freight transportation and rural transportation. Considering the availability of data and the feasibility of practical operation, city road traffic has become a favorite object of study for many scholars. However, with the improvement of the living standard, current rural motor vehicle ownership has risen sharply, and the problem of rural traffic carbon emissions has become increasingly prominent. In addition, with the development of the logistics industry, freight demand is increasing. The per-unit carbon emissions of freight vehicles are far greater than those of passenger vehicles (Bárzaga-Castellanos, 2001), and freight transport carbon emissions need more attention.

(4) The quantitative research on the effect of road traffic policy will be the focus of future research. Currently, an awareness of the need for traffic abatement has been formed, and various emission reduction measures have also been developed. Nevertheless, these have failed to achieve substantial emissions reductions. Carbon emission control policies are often limited to the theoretical level, without consideration of the difficulties in implementing the policy process, such as the cost, availability of technology and other factors. Further research is needed to examine the practical application of policies designed to reduce carbon emissions.

Statement of exclusive submission

This paper has not been submitted elsewhere in identical or similar form, nor will it be during the first three months after its submission to the Publisher.

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Conflicts of interest

The authors declare that they have no conflict of interest.

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References

Al-Alawi, B.M., Bradley, T.H., 2013. Review of hybrid, plug-in hybrid, and electric vehicle market modeling studies. Renew. Sustain. Energy Rev. 21, 190–203.

Ang, B.W., Liu, N., 2007. Energy decomposition analysis: IEA mode versus other methods. Energy Pol. 35, 1426–1432.

Ang, B.W., Zhang, F., Choi, K.H., 1998. Factorizing changes in energy and environmental indicators through decomposition. Energy 23 (6), 489–495.

Arvin, M.B., Pradhan, R.P., Norman, N.R., 2015. Transportation intensity, urbanization, economic growth, and CO2, emissions in the G-20 countries. Util. Pol. 35, 50–66.

Auffhammer, M., Carson, R.T., 2008. Forecasting the path of China's CO2 emissions using province level information. J. Environ. Econ. Manag. 55, 229–247.

Bárzaga-Castellanos, L., Neufert, R., Markert, B., 2001. Life cycle assessment for the implementation of emission control measures for the freight traffic with heavy duty vehicles in Germany. Int. J. Life Cycle Assess. 6 (5), 285–292.

Batterman, S., Chambliss, S., Isakov, V., 2014. Spatial resolution requirements for traffic-related air pollutant exposure evaluations. Atmos. Environ. 94 (7), 518–528.

Büchs, M., Schnepf, S.V., 2013. Who emits most? Associations between socio-economic factors and UK households' home energy, transport, indirect and total CO2 emissions. Ecol. Econ. 90 (C), 114–123.

Burris, M., Nelson, S., Kelly, P., Gupta, P., Cho, Y., 2012. Willingness to pay for high-occupancy toll lanes. Transport. Res. Rec. 2297, 47–55.

Chai, J., Yang, Y., Lu, Q., Xing, L., 2015. Based on the impact of road transport needs of Bayesian structural equation modeling factors. Chin. J. Manage. Sci. 23, 386–390 (In Chinese).

Chen, X., Shao, S., Tian, Z., Xie, Z., Yin, P., 2017. Impacts of air pollution and its spatial spillover effect on public health based on China's big data sample. J. Clean. Prod. 142, 915–925.

Cheng, Y.H., Chang, Y.H., Lu, I.J., 2015. Urban transportation energy and carbon dioxide emission reduction strategies. Appl. Energy 157, 953–973.

Correia, G.N., Batista, T.P., Marques, S.S., Silva, C.M., 2014. How car material life-cycle emissions are considered in environmental rating methodologies? Suggestion of expedite models and discussion. Renew. Sustain. Energy Rev. 38 (5), 20–35.

Darido, G., Torres-Montoya, M., Mehndiratta, S., 2009. Urban Transport and Co2 Emissions: Some Evidence from Chinese Cities. World Bank discussion paper, pp. 55–73.

Dietz, T., Rosa, E.A., 1997. Rethinking the environmental impacts of population, affluence, and Technology. Hum. Ecol. Rev. 1, 277–300.

Dray, L.M., Schäfer, A., Benakiva, M.E., 2012. Technology limits for reducing EU transport sector CO2 emissions. Environ. Sci. Technol. 46 (9), 4734–4741.

Ehrlich, P.R., Holdren, A.H., 1970. Population, Resources, Environment: Issues in Human Ecology. Freeman, SanFrancisco.

Energy Law,http://www.zhb.gov.cn/gzfw_13107/zcfg/fg/xzfg/201610/t20161008_365106.shtml, 2016, 7. (Accessed 2016.11.26).

EPA, Environment Protection Agency, 2016. Fuel Economy Guide. US Department of Energy, Office of Energy Efficiency and Renewable Energy. https://www.epa.gov/environmental-topics/environmental-information-location (Accessed 2016.11.26).

Geng, J., Long, R., Chen, H., Li, Q., 2018. Urban residents' response to and evaluation of low-carbon travel policies: evidence from a survey of five eastern cities in China. J. Environ. Manag. 217, 47–55.

Geng, J., Long, R., Chen, H., Yue, T., Li, W., Li, Q., 2017. Exploring multiple motivations on urban residents' travel mode choices: an empirical study from Jiangsu province in China. Sustainability 9 (1), 136.

Geng, J., Long, R., Chen, H., 2016. Impact of information intervention on travel mode choice of urban residents with different goal frames: a controlled trial in Xuzhou, China. Transp. Res. Pt. A-Policy Pract. 91, 134–147.

Glassom, D., 2007. Transport and climate change: a review. J. Transport Geogr. 15 (5), 354–367.

Guo, B., Geng, Y., Franke, B., 2014. Uncovering China's transport CO2 emission patterns at the regional level. Energy Pol. 74, 134–146.

Hao, H., Liu, Z., Zhao, F., Li, W., Hang, W., 2015. Scenario analysis of energy consumption and greenhouse gas emissions from China's passenger vehicles. Energy 91, 151–159.

Hao, H., Wang, H., Ouyang, M., 2011. Fuel conservation and GHG (greenhouse gas) emissions mitigation scenarios for China's passenger vehicle fleet. Energy 11, 36–45.

Hillman, T., Janson, B., Ramaswami, A., 2011. Spatial allocation of transportation greenhouse gas emissions at the city-scale. J. Transport. Eng. 137 (6), 416–425.

Hughes, B., Chambers, L., Lansdell, H., White, R., 2004. Cities, area and transport energy. Road Transp. Res. 13 (2), 72.

Huo, H., He, K., Wang, M., Yao, Z., 2012. Vehicle technologies, fuel-economy policies, and fuel-consumption rates of Chinese vehicles. Energy Pol. 43 (2), 30–36.

Huo, H., Wang, M., 2012. Modeling future vehicle sales and stock in China. Energy Pol. 43 (3), 17–29.

Huo, H., Zhang, Q., Liu, F., He, K., 2013. Climate and environmental effects of electric vehicles versus compressed natural gas vehicles in China: a life-cycle analysis at provincial level. Environ. Sci. Technol. 47 (3), 1711.

International Energy Agency. http://www.iea.org/publications/freepublications/publication/co2-emissions-from-fuel-combustion-highlights-2017.html (Accessed 2018.3.31).

IPCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (Accessed 16.11.27).

Javid, R.J., Nejat, A., Hayhoe, K., 2014. Selection of CO2 mitigation strategies for road transportation in the United States using a multi-criteria approach. Renew. Sustain. Energy Rev. 38 (2), 960–972.

Johansson, B., 2003. Transportation fuels-a system perspective. Handbook Transp. Environ. 4, 141–158.

Jou, R.C., Chiou, Y.C., Chen, K.H., Tan, H.I., 2012. Freeway drivers' willingness-to-pay for a distance-based toll rate. Transp. Res. Pt. A-Policy Pract. 46, 549–559.

Kaika, D., Zervas, E., 2013. The Environmental Kuznets Curve (EKC) theory—Part A: concept, causes and the CO2, emissions case. Energy Pol. 62 (5), 1392–1402.

Kenworthy, J.R., Laube, F.B., 1996. Automobile dependence in cities: an international comparison of urban transport and land use patterns with implications for sustainability. Environ. Impact Assess. Rev. 16, 279–308.

Li, W., Ding, W., Nie, Y., Qi, X., Wu, G., Li, L., Liao, J., Chen, S., Wei, Z., 2016a. Enhancing the stability and activity by anchoring Pt nanoparticles between the layers of etched montmorillonite for oxygen reduction reaction. Sci. Bull. 61 (18), 1435–1439.

Li, W., Long, R., Chen, H., 2016b. Consumers' evaluation of national new energy vehicle policy in China: an analysis based on a four paradigm model. Energy Pol. 99, 33–41.

Li, Y., Song, J., Yang, J., 2014. A review on structure model and energy system design of lithium-ion battery in renewable energy vehicle. Renew. Sustain. Energy Rev. 37 (3), 627–633.

Liao, C., Lu, C., Tseng, P.H., 2011. Carbon dioxide emissions and inland container transport in Taiwan. J. Transport Geogr. 9, 722–728.

Litman, T., 2008. Smart transportation emission reductions: identifying truly optimal energy conservation and emission reduction strategies. Environment 13 (5), R101.

Liu, J., 2011. Chinese energy-saving potential in the transport sector and carbon emissions prediction. Resour. Sci. 33 (4), 640–646 (In Chinese).

Liu, T., Wang, Q., Su, B., 2016. A review of carbon labeling: standards, implementation, and impact. Renew. Sustain. Energy Rev. 53, 68–79.

Liu, Y., Xie, Y., 2013. Asymmetric adjustment of the dynamic relationship between energy intensity and urbanization in China. Energy Econ. 36 (3), 43–54.

Loo Becky, P.Y., Li, L., 2012. Carbon dioxide emissions from passenger transport in China since 1949: implications for developing sustainable transport. Energy Pol. 11, 464–476.

Lovins, A.B., Cramer, D.R., 2004. Hypercars, hydrogen, and the automotive transition. Int. J. Veh. Des. 35, 50–85.

Meng, J., Liu, J., Guo, S., Li, J., Li, Z., Tao, S., 2015. Trend and driving forces of Beijing's black carbon emissions from sectoral perspectives. J. Clean. Prod. 112, 1272–1281.

Mitchell, G., 2005. Forecasting environmental equality: air quality responses to road user charging in Leeds, UK. J. Environ. Manag. 77, 212–226.

Moriaty, P., Honnery, D., 2004. Forecasting world transport in the year 2050. Int. J. Veh. Des. 35, 151–165.

Nassani, A.A., Aldakhil, A.M., Abro, M.M.Q., 2017. Zaman K. Environmental Kuznets curve among BRICS countries: spot lightening finance, transport, energy and growth factors. J. Clean. Prod. 154, 474–487.

Newman, P., 2006. The environmental impact of cities. Environ. Urban. 18 (2), 275–295.

Ou, X., Zhang, X., Chang, S., 2010. Scenario analysis on alternative fuel/vehicle for China's future road transport: life-cycle energy demand and GHG emissions. Energy Pol. 38 (8), 394.

Pallavidino, L., Prandi, R., Bertello, A., Bracco, E., Pavone, F., 2014. Compilation of a road transport emission inventory for the Province of Turin: advantages and key factors of a bottom–up approach. Atmos. Pollut. Res. 5 (4), 648–655.

Paravantis, J., Georgaakellos, D., 2007. Trends in energy consumption and carbon dioxide emissions of passenger cars and buses. Technol. Forecast. Soc. Change 74 (5), 682–707.

Phu, N.V., 2010. Energy consumption and income: a semi parametric panel data analysis. Energy Econ. 32 (3), 557–563.

Poumanyvong, P., Kaneko, S., 2011. Does urbanization lead to less energy use and lower CO2 emissions? A cross -country analysis. Ecol. Econ. 70 (2), 434–444.

Puliafito, S.E., Allende, D., Pinto, S., Castesana, P., 2015. High resolution inventory of GHG emissions of the road transport sector in Argentina. Atmos. Environ. 101, 303–311.

Raslavičius, L., Azzopardi, B., Keršys, A., Starevičius, M., Ž, Bazaras, Makaras, R., 2015. Electric vehicles challenges and opportunities: Lithuanian review. Renew. Sustain. Energy Rev. 42, 786–800.

Reckien, D., Edenhofer, O., Ewald, M., Lüdeke, M.K.B., 2007. What parameters influence the spatial variations in CO2 emissions from road traffic in Berlin? Implications for urban planning to reduce anthropogenic CO2. Urban Stud. 44 (2), 339–355.

Schipper, L., Marie-Lilliu, C., Gorham, R., Agency, I.E., 2000. Flexing the Link between Urban Transport and CO2Emissions: a Path for the World Bank, vol. 3. IEA, pp. 319–335.

Schmidt, A., Rella, C.W., Göckede, M., Hanson, A., Yang, Z., Law, B.E., 2014. Removing traffic emissions from CO2, time series measured at a tall tower using mobile measurements and transport modeling. Atmos. Environ. 97, 94–108.

Schrank, D., Lomax, T., Turner, S., 2010. TTI's 2010 Urban Mobility Report. Texas Transportation Institute.

Shao, S., Tian, Z., Yang, L., 2017. High speed rail and urban service industry agglomeration: evidence from China's Yangtze River Delta region. J. Transport Geogr. 64, 174–183.

Singh, V., Sharma, S.K., 2014. Evolving base for the fuel consumption optimization in Indian air transport: application of structural equation modeling. Eur. Transp. Res. Rev. 6 (3), 315–332.

Song, M., An, Q., Zhang, W., Wang, Z., Wu, J., 2012. Environmental efficiency evaluation based on data envelopment analysis: a review. Renew. Sustain. Energy Rev. 16 (7), 4465–4469.

Song, M., Wu, N., Wu, K., 2014. Energy consumption and energy efficiency of the transportation sector in Shanghai. Sustainability 6 (2), 702–717.

Song, M., Zheng, W., Wang, Z., 2016. Environmental efficiency and energy consumption of highway transportation systems in China. Int. J. Prod. Econ. 181, 441–449.

Spielmann, M., Haan, P.D., Scholz, R.W., 2008. Environmental rebound effects of high-speed transport technologies: a case study of climate change rebound effects of a future underground maglev train system. J. Clean. Prod. 16 (13), 1388–1398.

Su, B., Ang, B.W., 2012. Structural decomposition analysis applied to energy and emissions: some methodological developments. Energy Econ. 34 (1), 177–188.

Sumaedi, S., Bakti, I.G.M.Y., Rakhmawati, T., Astrini, N.J., Widianti, T., Yarmen, M., 2016. Factors influencing public transport passengers' satisfaction: a new model. Manage. Environ. Qual. 27 (5), 585–597.

Sun, J., 1980. Accounting for energy use in China. Energy 23, 835–849.

Timilsina, G.R., Shrestha, A., 2009. Transport sector CO2emission growth in Asia: underlying factors and policy options. Energy Pol. 4523–4539.

Tolón-Becerra, A., Pérez-Martínez, P., Lastra-Bravo, X., Otero-Pastor, I., 2012. A methodology for territorial distribution of CO2, emission reductions in transport sector. Int. J. Energy Res. 36 (14), 1298–1313.

Viard, V.B., Fu, S., 2015. The effect of Beijing's driving restrictions on pollution and economic activity. J. Publ. Econ. 125 (8), 98–115.

Wang, L., Zhang, H., Liu, Y., 2014a. Study on influencing factors of carbon emission robustness in China based on EBA model. Geogr. Sci. 34 (1), 47–53.

Wang, S., Fang, C., Guan, X., Pang, B., Ma, H., 2014b. Urbanization, energy consumption, and Carbon dioxide emissions in China: a panel data analysis of China's provinces. Appl. Energy 136 (C), 738–749.

Wang, T., Li, H., Zhang, J., Lu, Y., 2012. Influencing factors of carbon emission in China's road freight transport. Proced. Soc. Behav. Sci. 43, 54–64.

Wang, W., Zhang, M., Zhou, M., 2011. Using LMDI method to analyze transport sector CO2 emissions in China. Energy 36, 5909–5915.

Wang, Y., Ma, W., Tu, W., Zhao, Q., Yu, Q., 2013. A study on carbon emissions in Shanghai 2000-2008, China. Environ. Sci. Pol. 27, 151–161.

Wu, L., Kaneko, S., Matsuoka, S., 2005. Driving forces behind the stagnancy of China's energy-related CO2, emissions from 1996 to 1999: the relative importance of structural change, intensity change and scale change. Energy Pol. 33, 319–335.

Wu, Y., Zhang, S., Hao, J., Liu, H., Wu, X., Hu, j., Walsh, M.P., 2017. On-road vehicle emissions and their control in China: a review and outlook. Sci. Total Environ. 574, 332–349.

Zhang, C., Nian, J., 2013. Panel estimation for transport sector CO2 emissions and its affecting factors: a regional analysis in China. Energy Pol. 63 (7), 918–926.

Zhang, L., Long, R., Chen, H., Yang, T., 2018. Analysis of an optimal public transport structure under a carbon emission constraint: a case study in Shanghai, China. Environ. Sci. Pollut. Res. 25, 3348–3359.

Zhang, T., Zeng, Y., 2013. Spatial econometric analysis of China's transportation carbon emissions. Urban development research 20 (10), 14–20 (In Chinese).

Zhang, X., Shao, S., Zhao, X., Jiang, Z., 2017. How to achieve the 2030 CO2 emission-reduction targets for China's industrial sector: retrospective decomposition and prospective trajectories. Global Environ. Change 5 (44), 83–97.

Zhang, X., Yang, M., Yan, Y., 2014. Urban transport energy consumption and carbon emissions of statistical calculation method. Chin. Soft Sci. 6, 142–150 (In Chinese).